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Review article

Smart homes and home health monitoring technologies for older adults: A systematic review

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ABSTRACT

Background: Around the world, populations are aging and there is a growing concern about ways that older adults can maintain their health and well-being while living in their homes.
Objectives: The aim of this paper was to conduct a systematic literature review to determine: (1) the levels of technology readiness among older adults and, (2) evidence for smart homes and home-based health-monitoring technologies that support aging in place for older adults who have complex needs.
Results: We identified and analyzed 48 of 1863 relevant papers. Our analyses found that: (1) technology-readiness level for smart homes and home health monitoring technologies is low; (2) the highest level of evidence is 1b (i.e., one randomized controlled trial with a PEDro score $\geq$6); smart homes and home health monitoring technologies are used to monitor activities of daily living, cognitive decline and mental health, and heart conditions in older adults with complex needs; (3) there is no evidence that smart homes and home health monitoring technologies help address disability prediction and health-related quality of life, or fall prevention; and (4) there is conflicting evidence that smart homes and home health monitoring technologies help address chronic obstructive pulmonary disease.
Conclusions: The level of technology readiness for smart homes and home health monitoring technologies is still low. The highest level of evidence found was in a study that supported home health technologies for use in monitoring activities of daily living, cognitive decline, mental health, and heart conditions in older adults with complex needs.

Contents

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1. Introduction

In many countries of the world, populations are aging at an increasing rate, as fertility rates decline and life expectancy rises [1]. As a result, the population ratio of older adults relative to the total population is increasing. According to a report released by the United Nations, the proportion of persons aged 60 years and older, compared to the total population, is expected to double between 2007 and 2050, and reach 2 billion by 2050 [2].

Placement in a care facility, especially when it occurs against an individual's wishes, has been associated with negative effects such as depression, social isolation, and greater dependency in completion of self-care tasks [3]. Therefore, older adults prefer to stay in their homes rather than enter a healthcare institution when they need specialized care. For example, in a survey undertaken in the United States, 30% of those over 65 years stated they would "rather die" than enter a nursing home [3]. Burden and costs of care not only rise in the healthcare system but also for informal caregivers (i.e., family members, friends, neighbours). The significant costs associated with the provision of care to an aging demographic, as well as shortages in the health workforce, have spurred both industry (e.g., Elite Care, Intel, Tunstall) and academia to undertake research on the efficacy and feasibility of health monitoring and assistance provided in the home environment [4].

To the best of our knowledge, no literature review about smart homes and home health-monitoring technologies have characterized the quality (as scientific evidence over health outcomes) of the studies carried out with these technologies or the level of technology readiness. The aim is to provide a comprehensive review that characterizes the state of the art of smart homes and home health monitoring technologies. The specific research questions of this review are:

1. What is the clinical evidence of the outcomes in studies on smart homes and home health-monitoring technologies for older adults with complex needs?
2. What is the level of technology readiness for smart homes and home health-monitoring technologies intended for older adults with complex needs?

This paper has six sections including the Introduction (Section 1). We present a general background about the concept of technologies for older adults in Section 2. Then we describe the data sources and method used to locate and select the relevant literature in Section 3. Next, we present the results, where the research questions are answered in Section 4. In Section 5, we identify the main research gaps and make suggestions for future research. Section 6 is our conclusion.

2. Theoretical background: gerontechnology, smart homes and home-based consumer health technologies for older adults

In the United States, the prevalence of multiple chronic conditions in older adults exceeds 60%. According to the American Geriatrics Society, complex needs are chronic conditions that frequently require services from different health care practitioners in multiple settings including frequent hospitalizations [5]. Older adults with complex needs are limited in their ability to perform basic daily activities due to physical, mental and psychosocial challenges requiring complex continuing care [5]. Technology tools provide the possibility for older adults with chronic conditions and complex needs to remain at home and maintain an acceptable quality of life [6,7]. Technological innovation for older adults is occurring at an unprecedented rate [8]. "Gerontechnology" is a term that combines gerontology and technology, coined to describe an interdisciplinary field of science for "designing technology and environment for independent living and social participation of older persons in good health, comfort and safety" [9]. The term "smart home" refers to a special kind of home or residence equipped with sensors and actuators, integrated into the infrastructure of the residence, intended to monitor the context of the inhabitant to improve his or her experience at home [10,6]. Smart homes can enable older adults to live independently at home longer and reduce their reliance on informal or formal caregivers, or allow caregivers to better care for older adults. These technologies have the potential to provide a cost-efficient approach to enhance one's quality of life and help older adults live safely in their homes [11]. A smart home can potentially provide a variety of services spanning from simple task automation (e.g., room-temperature control), to analysis or prediction of the location of a resident, to behaviour or health status recognition of an occupant living at home, with subsequent transmission of collected data for remote monitoring. In health care, there are two key applications for smart homes: "(a) home automation: remote or automatic control of devices, appliances, or systems at home to enhance an occupant's quality of life, or to manage energy consumption; and (b) monitoring wellness: monitoring an occupant's health-status to maintain his or her well-being" [11,p. 4].

Technologies can be used to monitor wellness of older adults with complex needs living at home. These are not necessarily embedded in the residence or building structure, but are designed for home use by older adults with complex needs and their families, and include wearable sensors to detect changes in vital signs [12]. Examples of home health-monitoring technologies are systems for physiological monitoring (*Phys*), functional monitoring and emergency detection and response (*Fx*), safety monitoring and assistance (*Saf*), security monitoring and assistance *(Sec)*, social interaction monitoring and assistance (*Soc*), and cognitive and sensory assistance (*Cog/Sen*) (see Table A.1 in supplemental material for more details) [10].

There are three steps involved in monitoring the health and well-being of older adults. First, one needs to monitor an occupant's context using a set of appliances (devices, objects), sensors and actuators in an array of heterogeneous sensor "*layer*" platforms (also called the "*acquisition layer*"). The communication with and among the devices, sensors, and actuator elements of a sensor platform uses wired or wireless protocols (e.g., Wi-Fi, Bluetooth, Zigbee, cable). Second, sensor data must be processed and analyzed to recognize the context of the inhabitant and environment (e.g., "*service layer*"). Third, applications available in the pervasive space ("*application layer*") activate and deactivate services and a graphical environment which helps make smart spaces "*visible*" to users [13]. Finally, all data gathered from this pervasive environment can be stored either locally or remotely in a database. The database can be processed and the derived knowledge can be used to alert caregivers by reporting an inhabitant's situation or triggering alarms (data transmission) [14] or the data could be used to control the environment to improve an inhabitant's experience [4,15]. For example, devices and actuators automate actions such as room temperature [16] or lighting control [13].

3. Data and methods

3.1. Data sources and search strategy

As smart home and home health-monitoring technologies research has been conducted in both health services and technology disciplines and scientific findings have been published in different literature repositories we decided to conduct our search in the following databases: *Scopus, PubMed, Cinahl, IEEE Explore, ISI Web of Sciences*, and *ACM Digital Library*. We undertook a search of literature published between 2010 to October 2014 related to technologies that support older adults in their living environment. Papers were extracted from databases using the following search terms alone or in four different combinations using the logical operators of "AND" and "OR": "smart home", "health", "gerontechnology", "assisted living", "tech*", "monitoring", "older adults", "telesurveillance", "telemonitoring", "older adult", "senior", "elderly". Table A.2 in the supplemental material presents terms used for different search queries.

3.2. Studies selection process

The database search and the initial removal of duplicates were performed by experienced researchers. Two independent researchers evaluated the titles and abstracts of the remaining articles and compared them to the inclusion and exclusion criteria. We paired each researcher with a research assistant. Both pairs of researcher and research assistant met to reconcile differences through discussion. If there was any disagreement on a paper's abstract suitability, the abstract was included. Next, the two researchers and two assistants reviewed the full texts of the selected papers. Each independently assessed a quarter of the papers to determine suitability for inclusion in data analysis. The same four independent raters completed data abstraction of the final selected papers, and annotated the operationalization of variables in a codebook. Finally, as a test of agreement between researcher and research assistant pairs during the full text articles review, and data abstraction, two new researchers independently reviewed 20% of randomly selected articles and 20% of all variable operationalization written in the codebook. In case of any disagreement regarding the suitability of a paper, we consulted a third researcher for an assessment of the paper. We selected the third researcher from an interdisciplinary panel of experts, with representation from the computing science and occupational therapy fields; they provided a final decision about whether or not to include a paper in the analysis (see Fig. 1 for more details). The level of agreement between the raters was excellent, i.e., 93.45% average agreement for abstracts (average kappa (κ) score of 0.807, $p < 0.000$), and 92.95% average agreement for full papers (overall average kappa (κ) score of 0.618, $p < 0.000$).

3.2.1. Inclusion criteria

1. Studies that included smart homes and home-health monitoring technology that:
   a. Addressed technology use in home or supportive care environments for older adults with complex needs (i.e., private residences, retirement villages, service-integrated housing and independent living facilities were considered as potential home environments) regardless of whether the technology was embedded in the building structure or was worn on the person;
   b. Addressed complex needs faced by older adults (physical, mental, or both); and
   c. Included technology (ies) that has been implemented or deployed at least in pilot form (with one older adult at a minimum) focused on supporting independence, or enabled collection of data for health monitoring or communication of older adults with complex needs.
2. Studies that included participants who were older adults with complex needs:
   a. Aged 60 years or older;
   b. Who required continuous care including permanent monitoring and who had chronic conditions generating limitations on their ability to perform basic activities of daily living (ADL[1]), and instrumental activities of daily living (IADL[2]) at home due to physical, mental or psychosocial impairments. If a given study addressed only one chronic condition such as COPD, diabetes or heart condition, we included the paper if it explicitly reported participants' limitations in performing basic ADL, instrumental ADL, or both, at home due to physical, mental or psychosocial impairments.
3. Studies published in English and available in full-text in peer-reviewed journals or conference proceedings from electronic abstract systems.
4. Papers that used any type of study design or methodology, with positive or negative results.

3.2.2. Exclusion criteria

1. Studies published in books, book chapters, PhD or Masters' theses.
2. Papers that were lecture notes in conferences, theoretical papers, narrative reviews, meta-analysis, and other types of literature review.
3. Research conducted in hospitals, nursing homes or rehabilitation facilities. These facilities were excluded because assistance (i.e., physical and psychological) was provided to residents in these settings [17].
4. Studies that were not health-related, focusing on home-based technology for other purposes such as energy efficiency or

[1] ADL (activities of daily living) are self-care activities such as bathing, dressing, eating, and personal grooming.

[2] Activities that are not necessary for fundamental functioning, but allow an individual live independently in a community. For example: taking medications, use of telephone or other form of communication or, using technology.

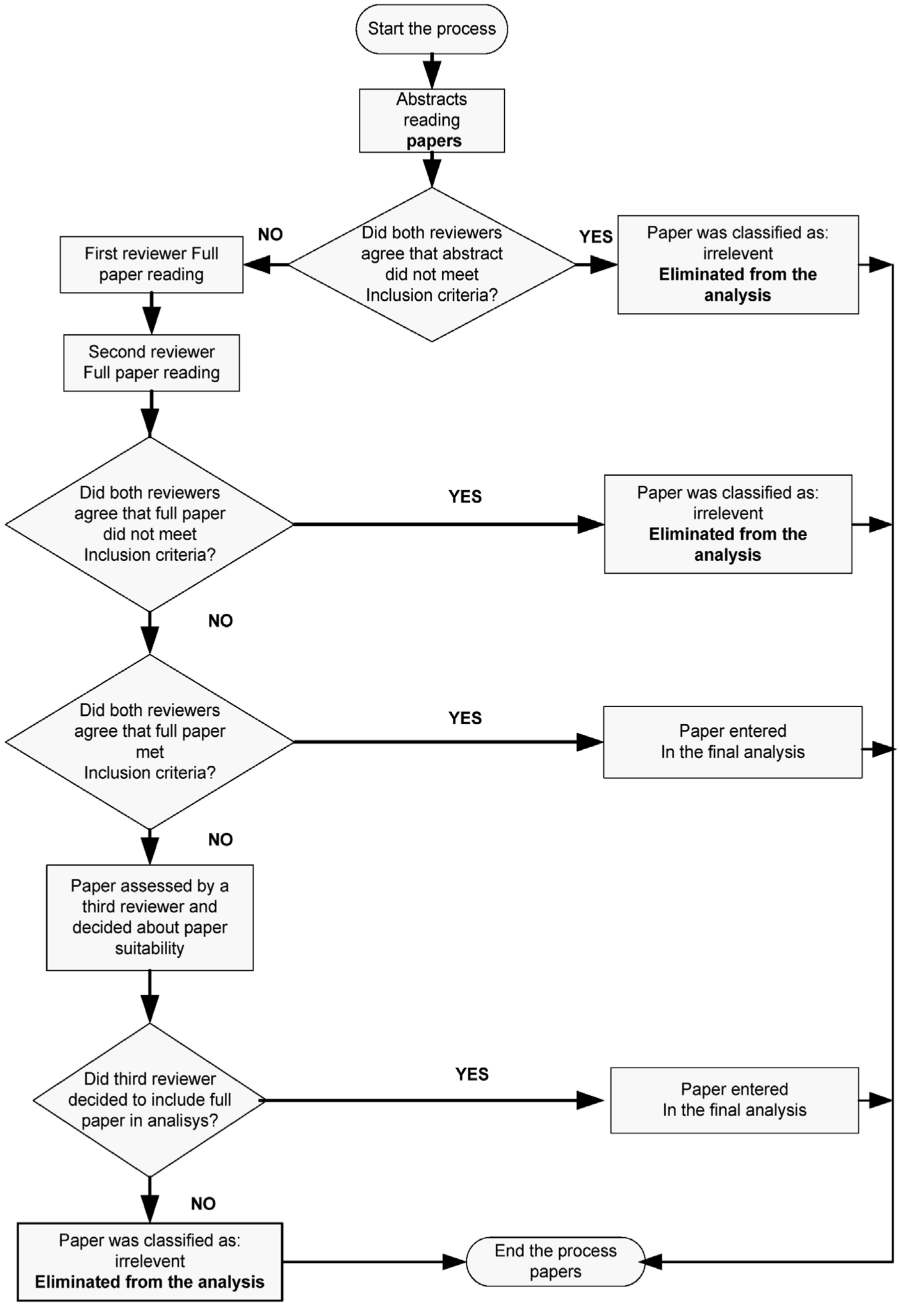

Fig. 1. Process flow of our literature review.

home security (e.g., sensors or cameras solely used to monitor either energy consumption or to detect intruders).

5. Studies on assistive devices such as canes, walkers, wheelchairs and hearing aids.
6. Studies on other types of technologies not related to smart home or home monitoring, e.g., Nintendo Wii.
7. Conference proceedings.
8. Abstracts or papers that were not available.
9. Studies published before 2010.
10. Papers on telemonitoring, telemedicine or telehealth programs that involved self-monitoring using lower complexity technologies such as interactive voice response protocols through landline phones or cell phones; blood pressure measurement using sphygmomanometers because we were interested in high tech applications that involved electronic data transmission.
11. Studies that reported mixed interventions (e.g., not control-case studies) including remote-monitoring technologies with other interventions such as home care education. Studies that incorporated interventions in addition to technologies under study would not allow us to know whether a change in the outcome was attributed to the technologies or to other interventions administered at the same time.
12. Papers that did not provide enough information for categorizing the paper (e.g., description of participants, technology readiness).

3.2.3. *Bias control*

By including a variety of databases, we were able to guarantee a more thorough search, to achieve greater levels of sensitivity, and to reduce source publication bias [18]. The inclusion of papers with positive and negative results eliminated the possibility of the publication bias described by Scherer et al. [19]. The inclusion of papers registered in electronic abstract systems was as the first '*quality filter*', ensuring some degree of scientific levels of conceptual and methodological rigor [20]. Studies published before 2010 were not included because, as suggested by [17], the rapid development of smart homes and home-based consumer health technologies utilized before this time would likely be obsolete. The exclusion of non-English papers from our sample represented only 0.48% of the total (see results section for more details). The inclusion of two pairs of raters during the selection process for relevant articles (i.e., abstract and full paper reading), and a third reviewer in case of disagreement, substantially reduced rater-bias that may have arisen from the subjective nature of applying the inclusion and exclusion criteria. Although inclusion criteria (1c) and (2a) may appear restrictive, we chose them because we were interested in knowing the actual levels of implementation, use, acceptance and effectiveness of smart home and home health-monitoring technologies for older adults with complex needs.

3.3. Publications review and data abstraction

Each selected paper was carefully reviewed for the following attributes: characteristics of the research conducted in smart homes and home health-monitoring technologies (i.e., therapeutic application and clinical implications (outcomes), sample size of studies, client age, and level of clinical evidence of outcomes), and features of smart homes and home health-monitoring technologies (i.e., level of technology readiness).

3.3.1. Characteristics of the research conducted in smart homes and home health-monitoring technologies

3.3.1.1. Type of study and level of clinical evidence and outcomes in the studies regarding smart homes and home health-monitoring technologies. The quality of a study was measured by the Physiotherapy Evidence Database (*PEDro*) scale.[3] This scale allows assessment of the quality of clinical trials in terms of a study's structure including randomization, blinding, attrition, design and statistics [21]. The PEDro scale has 11 criteria. Criteria 2–11 are rated "0" for "no" and "1" for "yes". Criterion 1 that relates to the generalizability of the trial was not used to calculate the PEDro score, thus, the maximum score that a trial can achieve was 10. Teasell and colleagues (2013) assessed the methodological quality of Randomized Controlled Trials (RCTs) based on their PEDro score. Scores of 9-10 were considered as "excellent" quality; 6-8 indicated "good" quality; 4-5 were of "fair" quality; and below 4 were "poor" quality. After assessing the clinical trials using the PEDro scale, we used an adaptation of the modified Sackett criteria proposed by Teasell et al. [22] in order to summarize the findings. Using these criteria, raters assigned a level of evidence for a given therapeutic intervention based on a 7 level scale. Table 1 shows the seven levels of evidence. The highest levels of evidence are achieved by RCTs and cross-over designs (1a, 1b) and, the lower levels are provided by quasi-experimental and uncontrolled designs (Levels 2–4) or, conflicting evidence [22]. As the field of smart homes and home health-monitoring technologies was broad in relation to the condition or behaviours addressed through these technologies, we assessed the levels of evidence for each condition or behaviour addressed in the papers analyzed in this review and associated the paper with the highest level of evidence achieved per condition or behaviour.

We collected data on *sample size, the length of the experiment* (in years), *type of topic or problem undertaken* (i.e., technology-oriented studies, clinical-oriented studies, usability, or a combination of them), *study design* (i.e., qualitative or quantitative research method), main *outcomes of the study*, and *setting where the technology was tested* (i.e., house, apartment etc.).

3.3.1.2. Condition/behaviors addressed or therapeutic application. This parameter refers to the type of need that was addressed by the proposed technology (e.g., falls prevention or detection, dementia support, chronic disease management, assisted living activities either for daily living (ADL) or instrumental activities daily living (IADL)).

3.3.2. Features of smart homes and home health-monitoring technologies

3.3.2.1. Level of technology readiness. This indicator assesses the maturity of evolving technologies during their development and early operations. We used the readiness scale of United States Department of Energy [23], in which 9 levels are used as follows: TRL1 (basic principles of technology are observed and reported); TRL2 (technology concept and/or application is formulated); TRL3 (analytical and experimental critical functions and/or characteristic proof of concept); TRL4 (component and/or system validation is conducted at laboratory environment); TRL5 (technology is developed and tested both in laboratory and validated in relevant environments); TRL6 (technology demonstration, in which engineering and pilot-scale, similar prototypical system validation in relevant environment is conducted); TRL7 (system commissioning I, in which full scale similar prototypical system is demonstrated in relevant environments); TRL8 (system commissioning II, actual system is completed and qualified through test and demonstration in relevant environments); and TRL9 (system operation, actual system operate over the full range of expected mission conditions).

3.3.2.2. Application of technology. This parameter refers to the classification provided by Ref. [10] for smart homes and home health-monitoring technologies. According to this classification, smart homes and home health-monitoring technologies were classified as either systems for physiological monitoring (*Phys*), functional monitoring/emergency detection and response (*Fx*), safety monitoring and assistance (*Saf*), security monitoring and assistance *(Sec)*, social interaction monitoring and assistance (*Soc*), or cognitive and sensory assistance (*Cog/Sen*) (see Table A.1 in Supplemental material).

3.3.2.3. Technology type used in the acquisition layer. This parameter refers to the name and technology used for sensing and capturing data (e.g., accelerometer, gyroscope, switches, magnetometer, pressure sensors, GPS, cameras).

3.3.2.4. Type of method used for communicating the data. This parameter refers to the protocol and system technology for communicating the captured data (e.g., Bluetooth, RFID, UWB radio, Wi-Fi, Zigbee, ultrasound, infrared).

3.3.2.5. Technology type used in the application layer to analyze and process the data. This parameter refers to the algorithms, computer programs, computing methods used for processing, transferring and storing data.

3.3.2.6. Approach or policy taken towards ethics and privacy of the individual. This parameter refers to whether any ethics and privacy issues were addressed or taken into account to guarantee a privacy-sensitive storage and communication of individual's data.

[3] The PEDro scale is a valid measure of the methodological quality of clinical trials. Available at: http://www.pedro.org.au/wp-content/uploads/PEDro_scale.pdf. Accessed on July 11, 2014.

Table 1
Levels of evidence [22[22, p. 9].

Levels of evidence	Number of RCT	PeDRO Scale Score	Additional characteristics
1a 1b	More than one One	6 or higher 6 or higher	Includes within subjects comparison with randomized conditions and crossover designs.
2	One	6	**Non-RCTS** and **Cohort studies** (using at least 2 similar groups with one exposed to a particular condition).
3	NA	NA	**Case-Control:** a retrospective study comparing conditions, including historical controls.
4	NA	NA	**Case Series:** retrospective chart review. **Pre-Post:** a prospective trial with a baseline measure, intervention, and a post-test using a single group of subjects. **Post-Study:** a prospective post-test with two or more groups, intervention. Post-test using a single group of subjects.
5	NA	NA	**Observational**, studies using **cross-sectional** analysis to interpret relations; **clinical consensus**, expert opinion without explicit critical appraisal, or based on physiology, biomechanics or "first principles"; or **Case Report, pre-post or case studies** (n = 1).
Conflicting	NA	NA	• Absence of evidence: agreement by a group of experts on the appropriate treatment course. • Disagreement between the findings of at least two RCTs. • Where there are more than four RCTs and the results of only one was conflicting, the conclusion was based on the results of the majority of the studies, unless the study with conflicting results was of higher quality.

4. Results

A total of 3378 papers were identified during the initial search phase. After removing duplicates the number of papers decreased to 1863. After applying the inclusion and exclusion criteria, only 48 of studies were included in the final analysis and data-abstraction phase (2.58%, 48/1863). We found 40 of the included papers in Pubmed (83.33%), 6 papers in CINAHL (12.5%) and, 2 papers ISI Web of Science (4.17%) (see Table A.3 in Supplemental material). Nine (only 0.48%) studies were excluded for not being in English (i.e., German, Italian, Portuguese, Spanish and Serbian). Therefore, the so-called Tower-of Babel bias described by Dickersin et al. [24] for excluding non-English language papers was minimal. Interestingly, half of the studies, i.e., 50.51% (941/1863) were excluded because the papers did not meet inclusion criteria (1c) or (2a) or both, i.e., the technology(ies) under study were not implemented or deployed at least in a pilot (TRL 5), participants did not have complex needs and were not aged 60 years or higher. Notably, 3% of the studies (57/1863) were removed due to exclusion criteria 12, i.e., after reading the full paper, there was not enough information for categorizing the paper (e.g., description of participants, technology readiness). Other relevant reasons for exclusion of papers from the final data-abstraction phase were that abstracts or papers were not available (5.1%, 95/1863), and papers were conference lecture notes, theoretical papers, narrative reviews, meta-analysis, or other types of literature review (5.9%, 111/1863). Fig. 2 shows a flow chart of the search and studies selection process.[4]

Of the studies included, 96% were journal papers and 4% were conference papers (see Fig. A.1 in Supplemental material for more details). Interestingly, in a linear regression carried out between the variables year of article publication versus number of papers published and analyzed, we found a positive correlation between these two variables (correlation coefficient b = +0.48, and proportion of the total variability $r^2 = 0.64$, $p < 0.000$). This means that although the total number of papers analyzed was small compared to the total sample after duplicates analysis (1863), there was a clear upward trend of number of published papers (see Fig. A.2 in Supplemental material for more details). Studies were characterized by low impact factor (i.e., SNIP mean 1.32 SD 1.86; 95% CI [0.73, 1.91]). However, the papers were published in journals located mostly in Q_1 journal quartile according to SJR journal classification [25]. Regarding the location of the home studies, we found that studies were undertaken in 16 different countries. Almost a half of the studies were conducted in United States of America (48% US), with 11% at multicenter or collaborations (see Fig. A.3 in Supplemental material for more information).

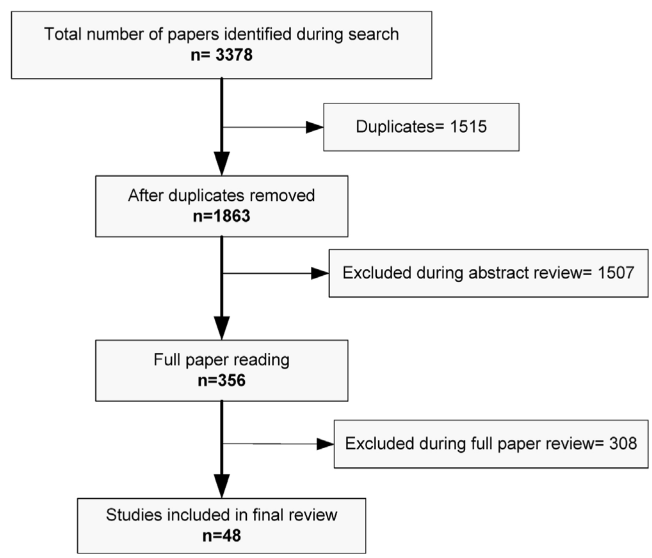

Fig. 2. Paper selection process of our literature review.

4.1. Descriptive analysis of studies

4.1.1. Characteristics of the research conducted in smart homes and home health-monitoring technologies

4.1.1.1. Smart homes and home health-monitoring technologies – age of participants, the size and the length of studies (number of participants/patients). The reviewed papers described studies with a mean age of participants of 75.40 years old (SD 7.17). The age ranges

[4] The% may not total 100% because several papers were excluded due to more than one inclusion or exclusion criteria.

were from 60 to 96 years, accounting for 11,282 participants in total, with a high dispersion in the number of participants, i.e., mean of n = 240.06 and SD 952.19. 68.75% of reviewed papers can be considered as small trials with a total number of participants <50 (i.e., mean n = 16.78 SD 12.7), whereas the remaining trials can be considered as medium-large (i.e., >50), with mean in the number of participants of n = 766.35 SD 1668.22 (see Table A.4 in Supplemental material for more detail). The lengths of the studies were diverse, with a mean of 0.82 years and a SD 0.92 years

4.1.1.2. Smart homes and home health-monitoring technologies—type of topic or problem undertaken. Almost 40% of the reviewed papers undertook the problem of technology acceptance, and 33.33% of studies reported investigation in terms of patients' clinical outcomes. However, only 2.08% of studies had incorporated any sort of economic analysis (see Table A.5 in Supplemental for more detail). Of all included papers, 60.41% used quantitative experimental design (randomized controlled trials, cross-sectional, descriptive, etc.), whereas, 35.42% of papers used qualitative experimental design (e.g., grounded theory, phenomenology, qualitative case study). In 4.17% of cases, studies used mixed methods. Only 18.75% of all papers reported outcomes of randomized controlled trials, the gold standard for medical and health research. The other two quantitative experimental designs with relatively high specific weight are technology feasibility studies (14.58%), and cross-sectional studies and one group pre-test post-test with a 6.25% of papers (see Fig. A.4 in Supplemental material for more details). There were four medical conditions or behaviours that smart homes/home health-monitoring technologies addressed, in which either no randomized controlled trial (RCT) had been conducted or RCT studies were still very few, i.e., diabetes type II, falls prevention, reduction of use of healthcare services, and cognitive decline and mental health (see Fig. A.5 in Supplemental material for more details).

4.1.1.3. Smart homes and home health-monitoring technologies—what are the outcomes?. Of the clinically-oriented and economic-assessment studies that reported any outcome (37.5%, n = 18), overall, 66.66% (12/18) of studies reported that the smart homes and home health-monitoring technologies showed advantages in terms of clinical outcomes compared to no intervention or other types of interventions (i.e., positive versus negative clinical outcomes was statistically significant, $\chi^2 = 5.56$, df = 1, $p < 0.05$, see Table 2a). This provides reasonable evidence for the feasibility of smart homes and home health-monitoring technologies (see Section 4.1.1.4 for more details). Tables 2a and 2b show the number of papers classifying the positive and negative outcomes per medical condition and disability addressed (n = 18), also, details about the total number of participants and study design type are provided.

4.1.1.4. Smart homes and home health-monitoring technologies—where is the evidence?. Research question 1: what is the clinical evidence of the outcomes in the studies regarding smart homes and home health-monitoring technologies for older adults with complex needs? Of the clinically-oriented and economic-assessment studies that reported any outcome (37.5%, n = 18), the evidence depends on the areas of medical conditions and disabilities addressed by *smart* homes and home health-monitoring technologies. Here, we present the highest level of evidence by condition (see Table 3).

Regarding monitoring of ADL, there was level 1b evidence from one RCT of excellent quality that demonstrated older adults maintained physical and cognitive status, and function in their ADL and mobility when a smart home system for functional monitoring was installed in a home.

There was conflicting evidence regarding home health-monitoring technologies for patients with chronic obstructive pulmonary disease (COPD). On one hand, there was level 1b evidence from a RCT of a good quality that indicated older adults with COPD experience a lower rate of exacerbations and hospitalizations when wearing a Bluetooth wristband that telemonitored their vital signs. On the other hand, there was level 1b evidence from a RCT of good quality to indicate that a home-health physiological monitoring system did not have any impact on the number of hospital admissions or hospital length of stay in older adults with COPD.

Regarding cognitive decline and mental health, there was level 1b evidence from a RCT of a good quality that older adults with chronic illness and comorbid depression exhibited reduced symptoms and post-discharge emergency-department visits due to the use of home health-monitoring technologies or devices for physiological and functional monitoring.

In the category of disease, disability prediction, health-related quality of life, there was level 1b evidence from a RCT of a good quality that use of technology to measure and track biometric data by itself did not improve or reduce the decline in frailty status in older adults.

Regarding fall prevention, there was level 2 evidence from a nonequivalent pretest-posttest control group design to indicate that the provision of a fall detector for older adults did not make a difference in reduction of fear of falling and in number of falls. However, older adults who used the device experienced improvements in safety, independence and confidence.

Finally, regarding monitoring of heart conditions, there was level 1b evidence from a RCT of a home health-monitoring system (wired blood-pressure monitor, wireless weight scale, a function programmed to ask participants about their health status, activities, and medication adherence, and that showed educational videos) that there was no statistically significant difference in rates of hospitalization, emergency department visits or death in older adults with heart failure who were monitored with a telehealth system compared with those who had case management. Under the same medical-condition category, there was level 1b evidence from a RCT of good quality that older adults with chronic kidney disease and hypertension using a wireless monitoring device improved sharing of data with the clinic and showed a trend toward improvements in blood pressure control.

We also did a correlation analysis between the level of evidence and the technology readiness level, and found a positive, statistically significant relationship between these two variables (Spearman rho correlation coefficient $r_{xy} = +0.533$, $p < 0.000$).

4.1.1.5. Smart homes and home health-monitoring technologies—usability and technology acceptance studies. Of the 48 studies included in this literature review, 66.67% of them (32 papers) aimed to study the usability and technology acceptance of smart homes and home health-monitoring technologies. Of these 32 papers, 21 (65.63%, 21/32) examined older adults' acceptance of monitoring technology (see Table A.6 in Supplemental material for more detail). In general, after analyzing the outcomes of this kind of studies one can say that acceptability and usability of these technologies were high among older adults. For example, in one study aimed to make a comparative evaluation of the interfaces of an enSAVE Ò-Prototype (wearable system), during and after the development, three-quarters of the older adults said they would use the service [45] (n = 22).

Another study that aimed to characterize older adult participants' perceived usefulness (n = 7) of in-home sensor data and to develop a novel visual display for sensor data from Ambient Assisted Living and Smart Homes showed that the participants' perceived usefulness was high [46]. As a result, the acceptability of this technology was also high because it allowed older adults

Table 2a
Positive and negative outcomes per Medical condition & disability addressed clinical-oriented and economic assessment studies (n = 18).

Medical condition & disability addressed	No. of papers (%)		Total no. of participants	Study type	Study
	Negative or mixed outcomes	Positive outcomes			
Monitoring of Activities of Daily Living	0 (0.0%)	2 (11.1%)	118	Case study, RCT	[26,27]
Chronic obstructive pulmonary disease	1 (5.6%)	1 (5.6%)	99	RCT	[28, **29**]
Cognitive decline and mental health	1 (5.6%)	2 (11.1%)	173	RCT, case study, one group pretest-posttest	[30 – **32**]
Disease/disability prediction/Health-related quality of life	2 (11.1%)	3 (16.7%)	9344	RCT, observational, nonequivalent pretest-posttest control group	[**33**, **34**, 35 – 37]
Fall Prevention	1 (5.6%)	2 (11.1%)	144	nonequivalent pretest-posttest control group, descriptive	[38–40]
Monitoring Heart conditions	1 (5.6%)	2 (11.1%)	749	RCT	[**41** – 43]
Total	6 (33.33%)	12 (66.66%)	10671		

Notes: Monitoring Heart conditions: heart failure, control of hypertension, monitoring heart conditions.
Disability prediction and health-related quality of life: social and spatial barriers/isolation reduction, self-perception of health wellbeing, monitoring overall health status, sleep problems, low physical activity, changes in activity patterns which can indicate emerging health problems, rate of deterioration into frailty state and death (weight loss, weakness, exhaustion, low activity, slow gait speed) cognitive decline and mental health: depressive symptoms, chronic conditions, dementia, wandering detection, slight cognitive decline). Paper in **bold** indicates negative outcomes or none significant differences were found.
RCT: randomized controlled trial.

Table 2b
Medical conditions and disabilities addressed and main outcomes.

Medical condition & disability addressed	Study	Main outcome(s)
Monitoring of Activities of Daily Living	[26]	Cost savings were achieved in all cases, and the benefits to older people and their caregivers were also considerable.
	[27]	The treatment group maintained physical and cognitive status, whereas the control group declined significantly in both.
Chronic obstructive pulmonary disease	[28]	The patients experienced a lower rate of exacerbations and Chronic obstructive pulmonary disease related hospitalizations compared to patients followed up using the standard model of care
	[29]	No statistically significant differences in the number of Chronic obstructive pulmonary disease related hospital admissions, length of stay between treatment and control group
Cognitive decline and mental health	[30]	**(1)** Lower emergency department usage rates for older adults, **(2)** improved the clinical and healthcare use outcomes for depressed older adults receiving homecare.
	[31]	**(1)** The system detected that patient was very active, **(2)** reduced the care visits, it save $2500 (pounds); and **(3)** reduced the felling of intrusion of caregivers
	[32]	No change was reported in the elders' quality of life and daily activity abilities.
Disease/disability prediction/Health-related quality of life	[33]	Home telemonitoring in older adults with multiple co morbidities does not significantly improve self-perception of mental well-being.
	[34]	The use of technology to measure and track biometric data by itself does not improve or lessen the decline in frailty status
	[35]	The telemonitoring system in rural agencies reduced the number of nursing visits and the overall cost of care
	[36]	Automatic monitoring of movement allowed early detection of dementia
	[37]	Reduction in hospitalization rates among the telehealth group compared to the non-telehealth group
Fall Prevention	[38]	Dynamic assessment of the variability of everyday movements, when combined with other known risk factors for falls, can significantly improve the accuracy of fall prediction
	[39]	The balance testing apparatus detected balance issues and demonstrated to be an effective method for monitoring balance and fall risk remotely
	[40]	(1) Both intervention and control groups experienced a reduction in fear of falling and also in fall reduction, and (2) Improvements in safety, independence and confidence.
Monitoring Heart conditions	[41]	No significant difference in rates of hospitalization, emergency department visits, death between intervention(telehealth case management) and control group (case management)
	[42]	Telemonitoring facilitated better ambulatory management of heart failure patients, including fewer emergency department visits
	[43]	The Blood Pressure statistically significantly decrease in both groups but participants using this device transmitted more than 30 BP readings/m

and family caregivers, to manage one's health and activity patterns, and identify changes in health status (sleep patterns). In another study that examined the usability of a fall detector (n = 47) for older adults, 58% of participants perceived that they had improved independence with use of technology. Moreover, 61% considered that it had improved their safety, 72% of them felt more confident with

Table 3
Level of Evidence Scale per Medical condition & disability addressed clinical-oriented and economic assessment studies (n = 18).

Medical condition & disability addressed	No. of papers	Technology readiness level	Study type	PeDro Scale	Level of Evidence Scale	Study
Monitoring of Activity Daily Living	2	9	RCT	10	**1b**	[27]
		9	Case study	NA	5	[26]
Chronic obstructive pulmonary disease	2	8	RCT	7	**1b**	[44]
			RCT	6	**1b**	[29]
Cognitive decline and mental health	3	9	NA	NA	5	[31]
		9	RCT	8	**1b**	[30]
		9	One group pretest-Posttest	NA	4	[32]
Disease/disability prediction/Health-related quality of life	5	9	RCT	4	2	[33]
		7	RCT	6	**1b**	[34]
		7	Non-equivalent pretest-posttest control group	NA	2	[35]
		6	Observational	NA	5	[36]
		9	Retrospective	NA	3	[37]
Fall Prevention	3	8	Predictive correlational	NA	4	[38]
		5	Descriptive	NA	5	[39]
		9	Non-equivalent pretest-posttest control group	NA	2	[40]
Monitoring Heart conditions	3	7	RCT	4	2	[42]
		7	RCT	6	**1b**	[41]
		9	RCT	6	**1b**	[43]

Notes: RCT: randomized controlled trial.
Level of evidence scale cell highlighted in bold means the highest level of evidence in this category.

the use of the technology, and 90% of them were pleased that they had a fall detector [40]. One study assessed the perceptions and expectations of seniors concerning technology installed and operated in their homes (n = 15). Participants stated that they accepted the smart home because they had the perception that these types of technologies would: (1) benefit them in an emergency, (2) provide assistance with hearing and visual impairment, (3) prevent and detect falls, (4) monitor physiological parameters (e.g., blood pressure, glucose levels), (5) provide safety control, (6) ensure property security (i.e., intruder alarm), (7) announce upcoming appointments or events, and (8) provide timely and accurate information on adverse drug events and contraindications [47].

Participants in usability studies highlighted barriers that hindered the use of smart homes and home health-monitoring technologies. For example: (1) participants stated that they were reluctant to accept the smart homes and home health-monitoring technologies if these technologies did not allow them to remain in their own homes and to age in place; (2) participants would only accept technologies if they improved their quality of life (i.e., high perception of usefulness) [47,48]; (3) in some studies participants felt anxious either due to loss of privacy (i.e., possible privacy violation resulting from the use of camera) [49] or due to the risk that their information would fall to people or organizations with no authorization to use it [50]; (4) some technical problems persist, such as cohabitation or multiple individuals residing in a single dwelling can result in sensors failing to correctly detect daily activities [12], buttons on the touch screen too small, incorrect feedback messages [51], level of false alerts can cause distress to users [40], the low-power wireless connection of low cost devices makes a system unreliable during long-term home usage [52]; (5) technologies under test were in their initial development stages and did not monitor or take into account all the aspects participants felt as very important for them [53]; (6) users' personal characteristics, including age, gender, cognitive abilities and personality traits, influenced users' success with technologies under study [54]; and, (7) participants considered some technologies as obtrusive systems [45]. Notably, none of these studies on usability and technology acceptance was quantitative, and they were conducted with low sample sizes. Further, none of them was based on theories that helped to explain intention to use and the usage behaviors of participants.

4.1.1.6. Smart homes and home health-monitoring technologies: targeted users and environments. In 75% of the papers, the smart homes and home health-monitoring technologies were oriented toward satisfying individuals' needs, in other words, to support physical or mental health, and to maintain independence and quality of life in their own living environment. In the remaining 25% of the papers, the technologies were oriented toward supporting individuals and either formal, informal or family caregivers. With respect to targeting users, in 87.5% of the papers, the smart homes and home health-monitoring technologies were installed or tested in either home, private dwellings or independent retirement facilities, whereas only 6.25% of the smart homes and home health-monitoring technologies were installed or tested in assisted living facilities (see Tables A.7 and A.8 in Supplemental material for more details).

We found a statistically significant and moderate positive correlation between targeted environments and targeted users variables (Spearman rho correlation coefficient $r_{xy} = +0.301$, $p < 0.043$). This reinforced the older adults' primary criteria about the use of smart homes and home health-monitoring technologies, i.e., participants in the analyzed papers stated that they accepted smart homes and home health-monitoring technologies only if these allowed to them to remain in their own homes and to age in place.

4.1.1.7. Smart homes and home health-monitoring technologies—medical condition/disability addressed. Table 4 and Fig. 3 show the type of medical condition and disability addressed by the proposed technology. From this table, one can see that Monitoring of Activities of Daily Living and, Disease/disability prediction/Health-related quality of life categories are associated with the highest number of papers, i.e., 27.08% and 22.92% respectively. Fall prevention (16.67%), and Cognitive decline and mental health (12.50%) are the two others important

Table 4
Condition/behaviors addressed by technologies (n = 48).

Medical condition & disability addressed	No. of papers (%)	Total number of participants	Total number of participants Mean (SD)	Study
Monitoring of Activities of Daily Living	13 (27.08%)	277	17.46 (29.6)	[26,27,49,51,55–63]
Disease/disability prediction/Health-related quality of life	11 (22.92%)	9527	866 (1893.16)	[29,33–37,52,53,64,65,66]
Fall prevention	8 (16.67%)	269	33.63 (26.72)	[38,39,40,46,67,68,69,70]
Cognitive decline and mental health	6 (12.50%)	312	52 (50.77)	[30–32,50,71,72]
Monitoring Heart conditions	4 (8.33%)	771	192.75 (187.68)	[41–43,45]
Diabetes Type II	2 (4.17%)	38	19 (12.72)	[54,73]
Do not report	2 (4.17%)	38	19 (5.65)	[47,48]
Chronic obstructive pulmonary disease	2 (4.17%)	143	99 (38.89)	[28,44]

Notes: monitoring heart conditions (i.e. heart failure, control of hypertension, monitoring heart conditions).
Disability prediction and health-related quality of life: social and spatial barriers/isolation reduction, self-perception of health well-being, monitoring overall health status, sleep problems, low physical activity, changes in activity patterns which can indicate emerging health problems, rate of deterioration into frailty state and death (weight loss, weakness, exhaustion, low activity, slow gait speed)).
Cognitive decline and mental health: depressive symptoms, chronic conditions, dementia, wandering detection, slight cognitive decline).

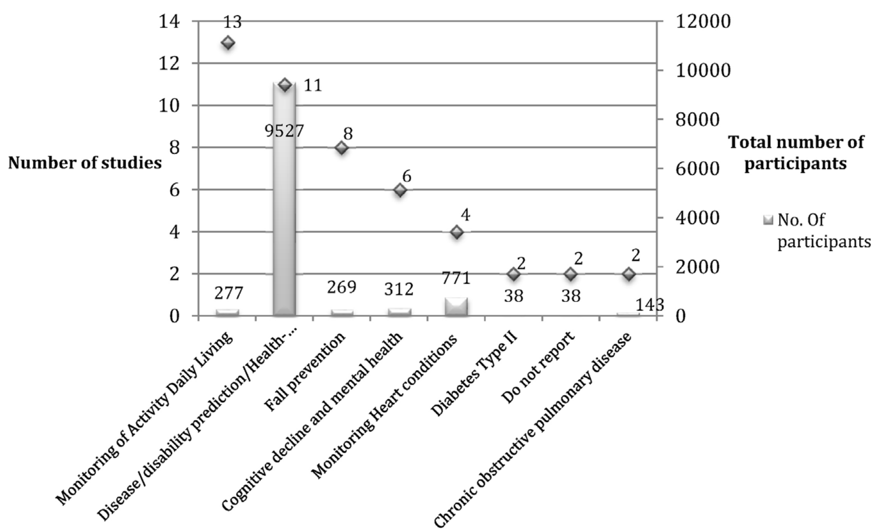

Fig. 3. Number of studies and the total number of participants per condition/behaviors addressed by in the areas of smart homes and home health monitoring technologies (n = 48).

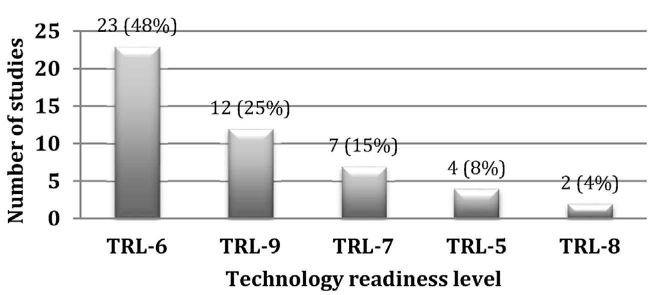

Fig. 4. Technology readiness level (n = 48) [23].

medical condition and disabilities to which smart homes and home health-monitoring technologies have been applied.

4.1.2. Features of smart homes and home health-monitoring technologies

4.1.2.1. Smart homes and home health-monitoring technologies—technology readiness level (TRL). Fig. 4 shows the level of technology readiness of the papers included in our analysis according to the scale of United States Department of Energy [23]. For research question 2, we asked, "What is the level of technology readiness for smart homes and home health-monitoring technologies for older adults with complex needs?" One can say that 56% of the studies were still either in development and testing phases in laboratory and validated in relevant environments (TRL5); or the technologies were in demonstration or pilot phase, and prototypical system validation in relevant environments (TRL6). The remainder 44% of smart homes and home health-monitoring technologies in the analyzed studies were mature technologies in which the actual system operates over the full range of expected mission conditions (TRL7, 8, and 9). Fig. 5 shows the technology readiness level versus number of participants per condition or behavior addressed. From this figure, one can reach the conclusion that the types of conditions or behaviors addressed by smart homes and home health-monitoring technologies that have greater levels of technology readiness were disease/disability prediction/health-related quality of life, chronic obstructive pulmonary disease, and monitoring of heart conditions.

In general, we found a statistically significant positive correlation between level of technology readiness and number of participants in the experiments conducted (Spearman rho correlation coefficient $r_{xy} = +0.439$, $p < 0.002$). In addition, we found a statistically significant positive association between the level of technology readiness (8 and 9) and the study type, i.e., randomized controlled trials (Pearson $\chi^2 = 5.998$, $p < 0.014$, $df = 1$, Phi association coefficient = +0.451). In other words, randomized controlled trials were conducted to assess technologies in the highest technology-readiness levels (8 and 9). We also find a significant positive association between the level of technology readiness (6) and the study type, i.e., technology feasibility (Pearson $\chi^2 = 11.357$,

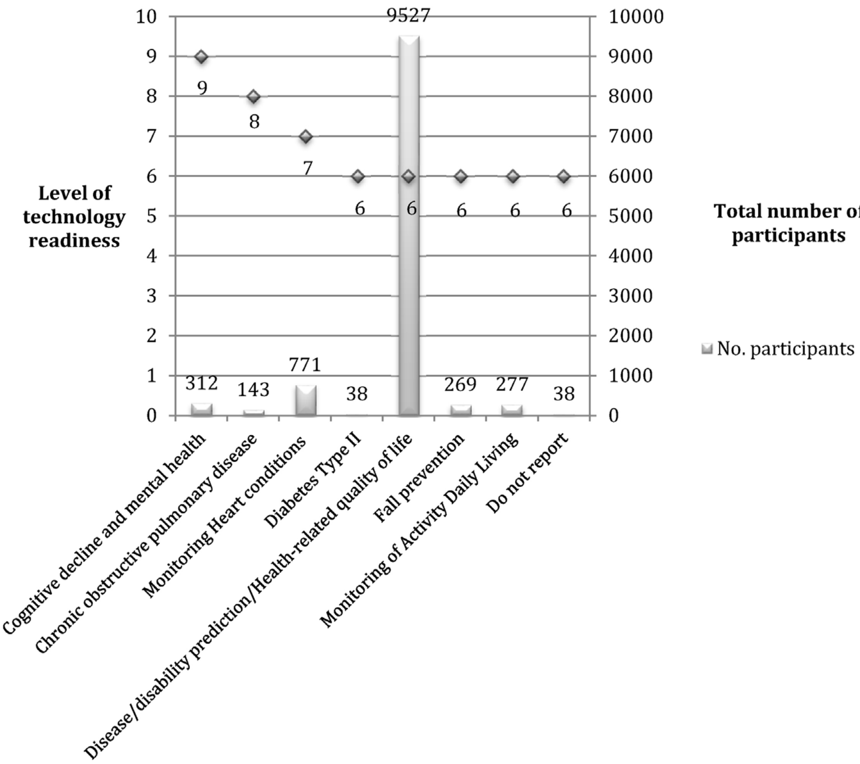

Fig. 5. Technology readiness versus number of participants per condition/behaviors addressed by in the areas of smart homes and home health monitoring technologies (n = 48).

$p < 0.001$, $df = 1$, Phi association coefficient = +0.621). In other words, the technology-feasibility studies were conducted when technology was implemented in pilot studies at small-scale trials.

4.1.2.2. Smart homes and home health-monitoring technologies—application. The most and the least used applications of smart homes and home health-monitoring technologies were physiological monitoring (Phys) and cognitive and sensory assistance (Sen), presented in 41.7% and 2% of the studies analyzed respectively. In addition, 61% of studies analyzed had only one type of application (i.e., functional monitoring/emergency detection and response component (Fx, 34%), physiological monitoring (Phys, 23%), safety monitoring and assistance (Saf, 2%), social interaction monitoring and assistance (Soc, 2%)); and 39% of studies analyzed examined more than one type of application. Only 8.0% of the studies had 3 or more applications: physiological monitoring, functional monitoring/emergency detection and response component, and safety monitoring and assistance (Phys, Fx, Saf, 4%); physiological monitoring, functional monitoring or emergency detection and response component, and safety monitoring and assistance (Phys, Fx, Saf, Sec, 2%); and physiological monitoring, functional monitoring/emergency detection and response component, safety monitoring and assistance, social interaction monitoring and assistance, and cognitive and sensory assistance (Phys, Fx, Saf, Soc, Cog/Sen, 2%) (see Fig. A.6 in Supplemental material for more details).

4.1.2.3. Smart homes and home health-monitoring technologies—technology type used. In examining the technologies used in smart homes and home health-monitoring technologies, it is worth examining the technologies used in the acquisition layer, in the application layer (to analyze and process the data gathered), and the types of methods used to communicate the data.

Stand-alone devices and computers either connected to a set of sensors or combined with additional devices (i.e., pulse-oxymeter, blood pressure cuff, stethoscope, pneumotachograph, electrocardiogram, thermometer, scales) were technologies most frequently used in the acquisition layer in smart homes and home health-monitoring technologies. These two modalities of technology type used in the acquisition layer in smart homes and home health-monitoring technologies accounted for 66.66% of studies analyzed. A total of 7 papers (14.58%) reported the use of cameras and video in the acquisition layer for monitoring the special needs in older adults. A distinctive aspect of this literature review is the use of mobile technologies in combination with additional devices (i.e., pulse-oxymeter, blood pressure cuff, stethoscope, pneumotachograph, electrocardiogram, thermometer, scales), as technology type used in the acquisition layer. However, mobile technologies in combination with these additional devices were used only in 8.3% (4 papers) of the studies analyzed. This seems to be a contradiction in an era when mobile technologies are ubiquitous. Regarding the type of software used in the application layer to analyze and process the data gathered, it was found that 43.75% of papers did not report the specific type of software used in the application layer, 14.6% of papers used web applications through broadband internet connection for administration and data access, and the remaining 31.75% used custom-made software for administration and data access. Of the papers under study, 41.6% reported that smart homes and home health-monitoring technologies used internet for external transmission of data (27.1% used solely internet, 13/48) and, internet in combination with either Bluetooth or Zigbee wireless platform for data transmission between the physical and the application layer (i.e., 14.5%, 7/48) (see Table A.9 in supplemental material for more detail).

4.1.2.4. Approach/policy taken towards ethics and privacy of the individual. Table 5 shows the approach or policy taken to guarantee privacy of an individual either in communication or storage of information processes. Almost a quarter of the papers reported any kind of approach or policy taken to guarantee privacy of the individuals

Table 5
Approach/policy taken towards ethics and privacy of the individual that use smart homes and home health monitoring technologies.

Ethics and privacy	No. of papers (%)	Technology Readiness (mode)	Study
Not reported	35 (72.92%)	6	[26–29,31–33,35–42,45–49,51–54,56,57,63,64,66–68,69,70,72,73]
Storage of data	5 (10.42%)	6	[34,43,44,58,59]
Communication + Storage	4 (8.33%)	6	[50,55,62,65]
Communication, transmission of data	4 (8.33%)	6	[30,60,61,71]

that used smart homes and home health-monitoring technologies. The most common approaches were: (1) removal of user identity and data encryption using unsupervised learning (Continuous Varied Order Multi Threshold Method (COM)) [55,65,58]; (2) in video-based fall detection, sensor algorithms were implemented to identify persons' patterns in the image that extract a silhouette of the person instead of using the real image [59]; and (3) web-site interfaces provided a secure interface to family members and individuals [43,62] (i.e., secure HTTPS protocol compliant login structure, according to Health Insurance Portability and Accountability Act of 1996—HIPAA).

5. Discussion

The aim of this systematic review was to examine evidence for home health technologies that support aging in place, and the level of technology readiness. To this end, we included 48 studies (out of 1863) from 2010 to October 2014. Specifically, we wanted to identify and characterize the best available evidence about the implementation of smart homes and home health-monitoring technologies and to respond to two research questions: (1) what is the clinical evidence of the outcomes in the studies regarding smart homes and home health-monitoring technologies for older adults with complex needs?; and (2) what is the level of technology readiness for smart homes and home health-monitoring technologies for older adults with complex needs?

To answer the first research question, we found that smart homes and home health-monitoring technologies have been used to address several medical conditions and disabilities. The highest level of evidence was 1b in regard to smart homes and home health-monitoring technologies used to monitor ADL, cognitive decline and mental health, and heart conditions in older adults with complex needs. The evidence supports that home health-monitoring technologies for cognitive decline and mental health reduce symptoms of depression and visits to the emergency department in older adults with chronic illness. There is evidence to support that technologies for monitoring heart conditions improve patients' sharing data with clinicians and their blood pressure control. There is no evidence that smart homes or home health-monitoring technologies help to address the conditions of disease or disability prediction, health-related quality of life or fall prevention. Finally, the evidence that smart homes or home health-monitoring technologies help to address the conditions of COPD is conflicting.

To answer the second research question, we can say that level of technology readiness for smart homes and home health-monitoring technologies *is still low*. We can assert this based on two facts. First, after removing the duplicated papers we had an initial potential sample of 1863 studies of which we had to exclude 591 papers (one third or 31.72%) because the studied technology(ies) *were not in at least pilot phase*. This means that one third of the studies that investigated smart homes and home health-monitoring technologies were conducted in artificial environments such as laboratories or academic institutions. In other words, these studies were in the stage of proof-of-concept or even cases of design projects that propose but not implement a system even in laboratory settings. Second, of the 48 papers in our literature review, the most common technology readiness level was 6, which means that technologies studied were implemented at a level that was located in the bottom or in the lowest level of the last third (the last third goes from level 5–9) of the technology readiness level scale [23].

The low number of studies included (48) in comparison with the initial potential sample of studies after duplicate removal (1863), revealed that although a large number of papers mentioned either in their titles or abstract the words "older adults", many of them included younger participants in the respective studies. In fact, out of the 356 full papers that were analyzed after the abstract filter, 69 were excluded because the participants were adults younger than 60 years of age. As a result, we want to issue a wake-up call on two aspects. First, when researchers analyze the scientific evidence of the outcomes in the application of smart homes and home health-monitoring technologies in older adults, they verify whether scholars agree on what age criteria defines "older adults". Second, despite the relevance of this topic, there actually exists little research on the measurement of the impact of technologies on older adults.

In our literature review, we excluded 3.1% of the studies because, after reading the papers, we did not have enough information (e.g., description of participants, technology readiness) to categorize the papers. Despite efforts in the standardization of good practices in reporting scientific papers in medical informatics such as [74,75], lack of quality in reports persists. This implies that the editors of journals indexed and conference proceedings reviewers must continue to improve the peer-review processes.

We found in our literature review a considerable number of studies (66.67%) dedicated to understanding how users accept home health technologies. In general, after analyzing the outcomes of these studies, one can say that the acceptability and usability of these technologies was high among older adults. Older adults highlighted that the main deciding factors, on whether to use or accept technologies, were that these technologies must allow them to remain in their own homes and to age in place, must improve their quality of life, and there must be a high perception of usefulness. Privacy is a major concern that hinders the adoption and the use of home health technologies, e.g., possible privacy violation resulting from the use of cameras. Major privacy concerns reported in these studies can be divided into two categories: (a) privacy of the occupant, and (b) security and privacy of the collected data. The privacy of the occupant should be considered both in details of collected data and type of devices and sensors. Traditionally, there are controversial privacy concerns when cameras are used to collect data. Therefore, many home health technologies should consider this issue in their design of data-capture methods and avoid using cameras or index frames for privacy protection and ethical reasons (e.g., capturing silhouettes instead of an image that allows the identification of the client).

None of the studies about usability of home health technologies included in this review used theories that helped to explain the intention to use and the usage behaviors in participants (e.g., Technology Acceptance Model (TAM-TAM2) [76], and the Unified Theory of Acceptance and Use of Technology (UTAUT) [77]). This is consistent with what was found in [78] where most of the papers in their literature review about acceptance of technology for aging in place by older adults lacked a theoretical approach. A theoretical framework in usability studies would allow researchers to achieve a better understanding about the reasons older adults accept or reject home health technologies.

We found that, in 75% of the papers, the smart homes and home health-monitoring technologies were oriented toward individuals, i.e., older adults. This means that designers of smart homes and home health-monitoring technologies were taking into account the main claim of older adults: they stated they were willing to accept the smart homes and home health-monitoring technologies if these allowed them to remain in their own homes and to age in place. As well, participants accepted technology if it was perceived to be useful and improved their quality of life [47,48]. We found that in 25% of papers, smart homes and home health-monitoring technologies were oriented toward supporting individuals and formal or informal caregivers, in contrast to other literature reviews that found few papers included caregivers as targeted users of smart homes and home health-monitoring technologies (e.g., Ref. [12]). Designers and developers of smart homes and home health-monitoring technologies appeared to understand that involving family members of older adults and other stakeholders is important for the success of such technologies, because their involvement allows older adults with cognitive and functional limitations to live in the community [12].

In our literature review, we found that only 2.08% of the included papers incorporated any sort of economic analysis. As evidence of cost-effectiveness is the most persuasive argument to motivate healthcare decision makers to implement at larger scale the home health technologies, more studies on cost-effectiveness analysis are needed. Other literature reviews assert that one of the factors leading to limited adoption of smart homes and home health-monitoring technologies are the lack of information related to technology costs and sustainable reimbursement models [12]. This can explain why we found a low level of technology readiness for smart home and home health-monitoring technologies.

We found a statistically significant positive association between the level of technology readiness (levels 8 and 9) and RCT study type, and a positive association between the level of technology readiness (level 6) and the "technology feasibility" study type. This is expected because technology-feasibility studies are conducted when a given technology is implemented in pilot studies on a small scale (i.e., technology readiness level 6), whereas RCTs are typically conducted to respond to more complex questions such as whether or not a given technology is effective or sustainable. This kind of question can be answered only when technologies achieve mature stages of implementation (technology readiness level 8 and 9). In addition, we found a statistically significant positive correlation between level of technology readiness and number of participants in the studies (Spearman rho correlation coefficient $r_{xy} = +0.439$, $p < 0.0.002$). It is expected that researchers want to demonstrate clinical evidence of smart home and home health-monitoring technologies with higher levels of implementation, therefore, they want to have larger sample sizes with randomized controlled trials.

Surprisingly, we found that in an era of ubiquitous mobile technologies, only four papers showed the use of smart mobile phones in combination with smart homes and home health-monitoring technologies for older adults. Computers such as desktop or laptop, and video communication, in combination with sensors or other devices were the most common devices used to implement the smart homes and home health-monitoring technologies solutions. Possibly, smart mobile technologies are more difficult to use and less accepted by older adults. Although there were few studies that reported the costs of implementation and development, low-cost, readily available technologies including a combination of the Internet, Zigbee, and Bluetooth were increasingly used.

Most of the papers were journal articles. Articles published in conference proceedings typically reported partial results, therefore, it was difficult to find in conference proceedings sufficiently detailed studies of smart homes and home health-monitoring technologies with technology readiness level higher than 5. Thus, papers of, or below, technology readiness level 5 were excluded during the selection process of this review. It seemed that results on proof-of-concept research (≤level 5) were published mainly as conference papers, while studies reporting clinical outcomes and usability results were published mainly as journal papers.

The origin of papers, according to the location of the authors, was 100% from developed countries. This is not surprising given the high cost of investigations on smart homes and home health-monitoring technologies, which prevents researchers from conducting such investigations in developing countries. Another possible explanation for the absence of authors from developing countries may be that the health systems of these countries have other priorities: (1) inequity in access, (2) the cost coverage, and the (3) quality of the health care systems. Thus, the resources of the systems in those contexts may not pay for these types of technologies or services that, in turn, affects the progress of research in this field. Other possible explanations may be sound intact family structures that reduce need for professional or automatized services, or life expectancies lower than 60 years of age in some developing countries which make smart homes and health-monitoring technologies not a research priority.

5.1. Gaps and implications for future research

- There is no evidence that smart homes or home health-monitoring technologies help to address the conditions of disability prediction and health-related quality of life or fall prevention, and there is conflicting evidence that home health technologies help to address the conditions of COPD. More RCTs on these topics would provide evidence to determine whether home health technologies are clinically effective to address these medical conditions. The conflicting evidence in the benefits of home health technologies for patients with COPD may be due to the field of telemonitoring interventions for patients with COPD is relatively new and presents some usability problems as Cruz and colleagues [79] pointed out.
- None of the studies about usability of home health technologies included in this review used theories for explaining the intention to use and the usage behaviors in participants. Usability studies should use a theoretical framework to explain the main determinants of smart homes and home health-monitoring technologies adoption. In addition, as most usability studies of home health technologies used qualitative approaches, an increase in quantitative research approaches in this topic will help to produce evidence on the adoption of home health technologies by users.
- Typically, the length of most studies was about one year (mode 1 year, and mean 0.82 years, SD 0.92 years). More longitudinal studies are required to gain an understanding of the effectiveness and sustainability of smart homes and home health-monitoring technologies on the functional status of older adults over several years.
- Economic assessment studies regarding the cost-effectiveness of smart homes and home health-monitoring technologies are still relatively rare (2.08%). More studies of this type are essential to provide high quality evidence of cost-effectiveness of smart homes and home health-monitoring technologies to guarantee a widespread adoption.
- The origin of the included papers was 100% from developed countries, therefore, it is necessary to promote the development and research of smart homes and home health-monitoring technologies in developing countries because the aging of the population

in developing countries [80] is becoming a demographic concern as it is in developed countries.

- There was a small number of studies that implemented low-cost technologies such as a combination of Internet plus Zigbee wireless platform and Bluetooth. If research and development of smart homes and home health-monitoring technologies continue using these low-cost technologies in clinical studies in real settings, they can achieve higher levels of technology readiness, i.e., TRL 5–6 or higher.

5.2. Study limitations

Our study suffers from some limitations. First, we acknowledge that we were unable to perform a meta-analysis because of the heterogeneity of the technologies used, the medical conditions and disability addressed with those technologies, and the outcomes reported in the studies included and reviewed. Second, there were a considerable number of parameters that could not be examined because the papers did not report them. Third, we were only able to assess quantitatively the strength of studies that used RCT due to the absence of standardized scales that determine the quality of either qualitative or quantitative non-RCT studies. Although there are guidelines, tools and checklists available for performing a critical appraisal of research literature, the result was a proxy measure of quality; without a scale, comparison of the relative quality of papers was not possible. Fourth, despite our use of a thorough search strategy, some empirical studies on smart homes and home health-monitoring technologies may not have been identified for this systematic review (e.g., gray literature such as unpublished documents and reports), because we only included papers that were published through the peer-review process.

6. Conclusions

- The level of technology readiness for smart homes and home health-monitoring technologies is still low.
- The highest level of evidence was 1b when considering whether home health technologies can help to address monitoring of ADL, cognitive decline and metal health, and heart conditions in older adults with complex needs.
- There is no evidence that home health technologies help address the conditions of disease or disability prediction and health-related quality of life or fall prevention.
- The evidence that home health technologies help to address the conditions of COPD is conflicting.
- The higher the level of evidence of experiments conducted in home health technologies, the higher the technology readiness level of these smart homes and home health-monitoring technologies (i.e., Spearman rho correlation coefficient $r_{xy} = +0.533$, $p < 0.000$).
- The smart homes and home health-monitoring technologies were oriented toward being installed or tested in either home, private dwellings or independent retirement facilities to be used directly for older users rather than for family caregivers ($r_{xy} = +0.301$, $p < 0.043$).
- The higher the number of participants in the studies conducted in smart homes and home health-monitoring technologies, the higher the level of technology readiness ($r_{xy} = +0.439$, $p < 0.0.002$).
- RCTs were conducted using smart homes and health-monitoring technologies of the highest technologies readiness levels (8 and 9). (Pearson $\chi^2 = 5.998$, $p < 0.014$ $df = 1$, Phi association coefficient = +0.451).
- Technology feasibility studies were conducted when smart homes and home health-monitoring technologies are implemented at pilot levels (TRL 5–6). (Pearson $\chi^2 = 11.357$, $p < 0.001$ $df = 1$, Phi association coefficient = +0.621).
- Although the total number of papers analyzed was small compared to the total sample after duplicates analysis (i.e., 1863), there is a clear upward trend in the number of published papers over the years ($\beta = +0.48$, $R^2 = 0.64$, $p < 0.000$).
- Economic-assessment studies regarding the cost-effectiveness of smart home and home-based technologies are still rare.

Summary points

What is already known on the topic?

- In many countries of the world populations are aging at an increasing rate.
- The proportion of persons aged 60 will reach 2 billion by 2050.
- "Gerontechnology" is a term that combines gerontology and technology.

What this study adds to our knowledge?

- Technology readiness for smart home and health monitoring technologies is still low.
- There is a high level of evidence for monitoring function, cognitive and mental health.
- There is minimal evidence technology predicts disability, prevents falls, helps quality of life.
- There is conflicting evidence home health technologies help conditions of chronic obstructive pulmonary disease (COPD).

Author contributions

LL, ES, and IN contributed to the conception of the study and to the text of the paper. AMRR and AMC contributed to the conception and text of the paper and performed the literature search.

Conflict of interest

The authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ijmedinf.2016.04.007.

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